a noise exposure threshold value for hearing conservation

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ABSTRACT

As part of a proposed EU directive for health and safety at work, a noise exposure threshold level of 75 decibels (A-weighted) over an 8-hour working day has been specified. This is stated to be the value below which continuous and/or repetitive exposure has no adverse effect on the health and safety of workers. This review considers the scientific background to the current international standard used to set the threshold level. Other literature data are reviewed, taking into account hearing loss due to the combination of natural ageing and exposure to noise. It is concluded that a threshold level of 75 dB(A) is overly conservative and that a daily noise exposure threshold level of 80 dB(A) can deliver suitable hearing protection.

KEYWORDS

Hearing loss, noise-induced hearing loss, noise, occupational noise exposure, exposure threshold level.

CONTENTS

SUMMARY

A draft health and safety directive, proposed by the European Commission, sets a threshold level of 75 dB(A) for an 8-hour workday as the exposure value below which continuous and/or repetitive exposure has no adverse effect on health and safety of workers.

This noise exposure target appears to be based on the International Standard ISO 1999, part of which deals with the estimation of noise-induced permanent threshold shift. An 8-hour exposure value of 75 dB(A) is deemed to produce no hearing damage.

The hearing loss portion of ISO 1999 is flawed. The mathematical model for estimating noise-induced hearing loss is based upon two incompatible data sets, one of which has been mistreated, while the other contains obvious errors.

Occupational hearing surveys show that daily noise exposures of 80 dB(A) or less do not produce detectable hearing loss at 4 kHz, the most noise-susceptible frequency, even after years of exposure.

Research on temporary threshold shift has indicated that broadband noise at 75 dB(A) does not produce measurable dullness of hearing at 4 kHz, even after 8-hour exposures. Noise of 80 dB(A) does produce a temporary threshold shift which recovers in a matter of minutes after the noise ceases.

The available scientific evidence indicates that the Threshold Level of the proposed directive has been set at a level so low that no hearing deficit would be anticipated, even in the most noise-susceptible portion of the population after a working lifetime of 40 years. The hearing protection aim of the proposed directive could be achieved with a noise exposure threshold level of 80 dB(A).

1. INTRODUCTION

In 1993, the Council of the European Communities issued a proposal for a directive regarding the exposure of workers to the risks arising from physical agents, one of which is noise (Commission of the European Communities, 1993: amended version, Commission of the European Union, 1994). The risks arising from noise exposure must be reduced to the lowest achievable level, with the aim of reducing exposure to below a Threshold Level. Considering the risk of noise-induced hearing loss, the threshold has been set at an $L_{EX,8h}$ value of 75 dB(A).[1] This risk reduction target is a standardised noise exposure level for a reference 8-hour workday.

The draft directive was accompanied by an Explanatory Memorandum which gave background on the aim of the proposal and the need for action, relying upon a draft International Standard (see International Organization for Standardization, 1982 and 1985). The Memorandum stated that, during the period leading up to the 1986 Council Directive on noise at work, “scientific and technical knowledge was already sufficiently advanced to make it possible to ascertain precisely the harmful effect of noise on hearing capacity. The scientific community had already established that, from 75 dB(A) on, the risks run by workers were far from negligible.” These statements may be challenged on several counts. Over the few years before the 1986 Directive, the exposure level 75 dB(A) was being proposed by some scientists as the threshold at which *no effect whatever* would be observed, even at the most vulnerable frequency 4 kHz. To imply that hearing risk, from that level upward, would be “far from negligible” is an unwarranted overstatement. The effect is progressive: there is no sudden jump from no effect to “far from negligible” as the threshold is crossed. A more accurate perception may be gained by considering the Threshold Level from both directions: *the value of noise exposure, above which hearing damage is measurable and significant, and below which no effects are discernible*. Furthermore, it is incorrect to say that scientific and technical knowledge allowed one to ascertain precisely the harmful effects of noise exposure. On the contrary, there were unexplained discrepancies in the scientific literature; many of these problems remain today.

This report is intended firstly to examine the hearing conservation potential of the 75 dB(A) exposure threshold of ISO 1999, which is the only universally accessible and workable document dealing with this matter (International Organization for Standardization, 1990). However, it will be shown that ISO 1999 is flawed: there is considerable uncertainty in the predicted magnitude of Noise-Induced Permanent Threshold Shift (NIPTS), particularly for low noise exposure levels.

Secondly, in this report a number of research studies and occupational hearing surveys are reviewed which post-date the development of ISO 1999, and in some cases the proposed Physical Agents Directive. These later studies enable one to assess the validity of the 75 dB(A) threshold of ISO 1999 and the proposed Directive.

[1] NOTE: The quantity $L_{EX,8h}$ is a noise exposure level, a notional constant noise lasting for a nominal 8-hour working day. The unit is the decibel corrected according to the A-weighting, a frequency response to account for the way the human ear perceives sounds of different frequencies.

2. THE PRELUDE TO ISO 1999

The idea of a noise threshold value of 75 dB(A) for hearing conservation purposes is not new. Such a value was suggested in Guignard (1973). "A level of 75 dB(A) sustained for 8 hours per day is the threshold for detectable NIPTS: exceeding that threshold may cause NIPTS exceeding 5 dB in up to 10% of the people after a cumulative noise exposure of 10 years."

Guignard's 75 dB(A) value also appeared in an important recommendation from the US Environmental Protection Agency (1974), to establish sound levels which would not adversely affect public health. Any measurable loss of hearing sensitivity, at any audiometric frequency, was deemed unacceptable; a NIPTS value of 0 dB was thought ideal, but not appropriate for several reasons. At the time, most audiometric instruments did not measure hearing levels in steps of less that 5 dB. In addition, there was no evidence to suggest that NIPTS of less than 5 dB would be perceptible by an individual with such a hearing loss. Therefore, an imperceptible NIPTS at the most noise-sensitive frequency 4 kHz was thought to be of no practical significance.

The EPA recommendation was based upon a synthesis (Johnson, 1973) of results from three occupational hearing loss surveys, one Dutch, one British, and one American. The survey results were summarised in a table giving the predicted maximum NIPTS in 90% of a noise-exposed population after a 40-year working lifetime in a range of average noise levels.

$L_{Aeq,8h}$	maximum NIPTS, 4 kHz
75 dB(A)	6 dB
80 dB(A)	11 dB
85 dB(A)	19 dB
90 dB(A)	28 dB

These predicted NIPTS values form the basis of the final recommendation for the noise exposure limit of 75 dB(A) for 8 hours, to protect the hearing of the American public "with an adequate margin of safety". The Dutch and British data were examined again by Johnson for the later International Standard ISO 1999.

3. HEARING DAMAGE PREDICTED BY ISO 1999

This section is intended to examine the 75 dB(A) exposure threshold of ISO 1999, which is the only universally accessible and workable document dealing with this matter.

3.1. THE NOISE THRESHOLD FOR MINIMUM PREDICTED HEARING DAMAGE

The first section of ISO 1999 contains statements which define the scope of the standard. In respect of estimating NIPTS from any given noise exposure, the scope may be summarised as follows:

- Formulae are presented to calculate NIPTS, for the audiometric frequencies 0.5 kHz to 6 kHz, attributable to noise exposures over each 8-hour working day, for periods of exposure lasting from 0 to 40 years. The calculation method uses the daily exposure level, termed $L_{EX,8h}$, over the limited range from 75 dB(A) to 100 dB(A). The formulae may be used to calculate the median NIPTS and the statistical distribution above and below the median. The values of NIPTS resulting from the calculation method are valid for both male and female populations.

Two points are worth mentioning here. First, NIPTS should not be confused with hearing threshold level. NIPTS may combine with age-associated hearing loss and any possible pathological overlay to give hearing threshold level. Second, the daily noise exposure level $L_{EX,8h}$ which appears in ISO 1999 and in this present document, is identical to the daily personal noise exposure level $L_{EP,d}$ used throughout the European Union since 1986.

A detailed examination of the calculated values of hearing thresholds depending on age, noise exposure, and the combination of these two factors is presented in **Appendix 1**. The following conclusions are drawn from this examination:

- ISO 1999 states a damage risk threshold $L_{EX,8h}$ equal to 75 dB(A). However, NIPTS is not predicted until an exposure of 78 dB(A) is reached.
- NIPTS values resulting from an $L_{EX,8h}$ of 80 dB(A) are small in comparison to the age-associated hearing loss of a **normal** population.
- NIPTS values resulting from an $L_{EX,8h}$ of 80 dB(A) are insignificant in comparison to the hearing loss associated with ageing, diseases, etc. in a **typical** or unscreened population.

3.2. DERIVATION OF ISO 1999 METHOD

The use of the international standard ISO 1999 in this report does not imply acceptance of its reliability. In fact, its derivation from experimental data is flawed in several respects, as outlined below.

The estimation of NIPTS in the standard uses a mathematical model derived by Johnson (1978), and is based upon a synthesis of two incompatible data sets, one from the UK, the other one from the Netherlands.

3.2.1. UK data

A field study of occupational hearing loss in approximately 1000 workers was reported by Burns and Robinson (1970). This work, performed in part by the National Physical Laboratory (NPL), led to a set of tables to allow easy estimation of hearing threshold levels in noise-exposed workers (Robinson and Shipton, 1977). These tables were used in Johnson's synthesis. The NPL tables give NIPTS for a screened normal population having a daily noise exposure of $L_{EX,d}$ for any given number of years. Audiometric frequency (0.5–6 kHz) and sex are accounted for; The overall hearing threshold level is obtained by adding a standard age factor. However, the noise and age components are notional factors separated for computational purposes only, with the statistical variation of both age and noise effects loaded onto the NIPTS factor alone. Nevertheless, Johnson attempted to generate independent distributions for the true age and noise components, to force the NPL data into a form compatible with information from the Netherlands (see below). To do this, he superimposed the arbitrary assumption that noise exposures of 75 dB(A), no matter for how long, produce no hearing loss. Using this assumption, Johnson was able to extract distributions of the age and NIPTS factors. This procedure was highly dubious, considering the stated nature of the data in the NPL tables, and also the fact that the NPL table values had to be extrapolated well below the range of noise levels actually encountered in the Burns and Robinson field studies.

The results of Johnson's manipulations are shown for 4 kHz in **Table 1a**, and deserve some comment. Trends in the values reflect features that can be observed in actual populations. Selecting any column of the table, the threshold shift increases with noise exposure levels as common sense dictates. A slightly less obvious trend of threshold shift may also be observed: note that NIPTS increases at a decelerating rate with time, e.g. for 90% (noise-resistant fractile), 100 dB(A), the values are

10	20	30	40	yr
10.8	14.5	17.4	18.9	dB

From any similar example in the table, it is seen that the greater threshold shift occurs in the first ten years of noise exposure. This is a well-established aspect of noise-induced hearing loss (NIHL).

Another subtle feature of the NIPTS distribution is also correctly reflected in the values of **Table 1a**. The distribution is slightly asymmetrical, with less variability amongst individuals who are resistant to noise than among those who are more susceptible. This can be seen from the different intervals, at any exposure duration and audiometric frequency, between the 90-percentile and the median values and between the median and the 10-percentile values.

3.2.2. Dutch data

Johnson's other starting point were data contained in a report by Passchier-Vermeer (1977), giving a synthesis of eight noise-induced hearing loss studies from the 1950s and 60s. The model of NIHL (based upon data from 2300 ears) was given in the form which Johnson desired, as separate distributions (90%, 50% and 10%) of NIPTS and age components, with overall hearing threshold levels obtained by summing at corresponding fractiles. The actual values for the noise component extracted from Passchier-Vermeer were median, 90% and 10% hearing threshold levels after 10, 20, 30 and 40 years exposure at various $L_{EX,8h}$ values.

Focusing on 4 kHz, the relevant data may be seen in **Table 1b**. Note that there is no variation over the 30-year span. For example at 100 dB(A) the noise component (NIPTS) is constant at 38.7 dB. This trend, or rather non-trend, occurs only at the most noise-susceptible frequency 4 kHz, and is clearly anomalous.

Examining **Table 1b**, it may be seen that trends differ from those in **Table 1a** in another important respect. The values are expected to increase as one scans from 90% through 10% in each cell of the table. This is seen, however, only at 10 and 20 years exposure; for long durations, it is reversed. For example, at 100 dB(A), 40 years, the values are

90%	50%	10%
42.3	38.7	34.7 dB

This is highly dubious, as it indicates that increasing noise duration actually *reduces* the degree of noise-induced hearing loss in the most susceptible 10% of the population. Such suspicious entries in **Table 1b** are given in **bold** type face.

There is another dubious trend which dominates the NIPTS data for 40 years duration. Note that the threshold values decrease (improve) as one scans from the better-hearing to worse-hearing deciles. This false trend, seen in the values given in *italic* type face, is clearly opposite to what it should be.

3.2.3. Johnson's synthesis

The data derived from the UK and Dutch sources were not in close agreement; in some cases, the corresponding values differ by over 20 dB. However discordant, the values were simply averaged by Johnson to provide a data field for his mathematical model. The input data for this modelling process are shown, for the example of 4 kHz, in **Table 1c**.

The curve-fitting procedure employed by Johnson introduced a further arbitrary assumption: there exists a threshold value L_0, below which NIPTS does not occur for any noise exposure duration, and above which the NIPTS increases as the square of the excess of $L_{EX,8h}$ over the threshold L_0. This model of NIPTS growth has no foundation in experiment. In defence of Johnson, it is clear that any higher level function could not be determined from the input data, in view of the discrepancies between the data sets and uncertainties within each set. The assumed model of NIPTS growth takes on particular significance when the results are used at or near the 'threshold' L_0, which is the focus of the present report.

CONCLUSION: The hearing loss calculation method for ISO 1999 is flawed, and there is a large underlying uncertainty of the magnitude of NIPTS. The method is untrustworthy, particularly for low noise levels.

Table 1a: One set of NIPTS data for 4 kHz, derived from Robinson and Shipton (1977)

Exposure duration, yr	10			20			30			40		
Fractile, %	90	50	10	90	50	10	90	50	10	90	50	10
$L_{\mathrm{EX,8h}}$, dB(A)												
75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.5	1.2	3.1	0.6	1.8	4.1	0.9	2.3	5.0	1.0	2.5	5.5
85	1.4	3.5	8.1	1.9	5.0	10.5	2.5	6.1	12.3	2.9	6.8	13.1
90	3.0	7.3	15.4	4.3	10.1	18.9	5.4	12.2	21.1	6.1	13.3	22.2
95	5.9	13.4	24.2	8.3	17.5	27.9	10.3	20.4	29.9	11.4	21.8	30.7
100	10.8	21.6	33.0	14.5	26.4	35.9	17.4	29.4	37.0	18.9	30.8	37.4

Table 1b: One set of NIPTS data for 4 kHz, derived from Passchier-Vermeer (1977)

Exposure duration, yr	10			20			30			40		
Fractile, %	90	50	10	90	50	10	90	50	10	90	50	10
$L_{\mathrm{EX,8h}}$, dB(A)												
75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	5.0	0.7*	0.0	5.0	0.0*	2.7	5.0	**7.6**	*5.6*	*5.0*	***5.0***
85	1.8	9.8	**16.5**	4.8	9.8	**13.8**	7.5	9.8	**11.4**	*10.4*	*9.8*	***8.8***
90	9.5	16.5	**22.7**	12.5	16.5	**20.0**	15.2	16.5	**17.6**	*18.1*	*16.5*	***15.0***
95	21.4	27.4	**32.1**	24.4	27.4	**29.4**	27.1	*27.4*	***27.0***	*30.0*	*27.4*	***24.4***
100	33.7	38.7	**42.5**	36.7	38.7	**39.7**	*39.4*	*38.7*	***37.3***	*42.3*	*38.7*	***34.7***

* These values were reported by Johnson (1978), and are consistent with the comparable entries in **Table 1c**. However, reference to the source document indicates that the two marked entries are incorrect; they should be **12.7** and **10.0**.

Table 1c: The means of the 4 kHz NIPTS values from Tables 1a and 1b; these were the input data for Johnson's curve-fitting procedure.

Exposure duration, yr	10			20			30			40		
Fractile, %	90	50	10	90	50	10	90	50	10	90	50	10
$L_{\mathrm{EX,8h}}$, dB(A)												
75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.3	3.1	1.9*	0.3	3.4	2.1*	1.8	3.7	**6.3**	3.3	3.8	**5.3**
85	1.6	6.7	**12.3**	3.4	7.4	**12.2**	5.0	8.0	**11.9**	6.7	8.3	**11.0**
90	6.3	11.9	19.1	8.4	13.3	**19.5**	10.3	14.4	**19.4**	12.1	14.9	**18.6**
95	13.7	20.4	28.2	16.4	22.5	**28.7**	18.7	23.9	**28.5**	20.7	24.6	**27.6**
100	22.3	30.2	37.8	25.6	32.6	**37.8**	28.4	34.1	**37.2**	30.6	34.8	**36.1**

* These values were reported by Johnson (1978), and are consistent with the comparable entries in **Table 1b**. However, the two entries marked above are incorrect; they should be **7.9** and **7.1**.

4. STUDIES OF PERMANENT HEARING LOSS FROM LOW-LEVEL NOISE

The very low exposures at or near the Threshold Level imply that very small values of NIPTS might be expected. If any effect is to be seen, then that effect will be most evident at 4 kHz.

4.1. HEARING LOSS FOR INDIVIDUAL FREQUENCIES

4.1.1. Passchier-Vermeer *et al* (1985), Passchier-Vermeer (1986)

Age-related hearing loss was investigated in Dutch samples not exposed to occupational noise, yielding data on the hearing thresholds for a typical unscreened population. These typical-for-age thresholds were then employed to show the effect of occupational noise upon hearing threshold levels of exposed workers.

Data were taken from 30 industrial hearing conservation programs, involving about 2000 male workers exposed to noise with level $L_{EX,8h} \geq 75$ dB(A). The noise exposure data gathered during the term of the study (1982-84) were used to represent the noise experienced by each worker over the course of his entire noise lifetime. The thresholds of the workers were corrected using the typical-for-age data to give the noise damage component of each worker's threshold. The study data were then subjected to curve-fitting analyses, with $L_{EX,8h}$ and noise-induced threshold shift as the independent and dependent variables, respectively. Curves were derived for noise durations of 10 and 40 years, and for the median (50%) threshold shift and for the 10% worst shift. The Dutch data, representing real hearing losses in noise-exposed workers, did not follow the predictions of ISO 1999: the survey data showed less NIPTS than predicted by the ISO calculation method.

For present purposes, the most useful curves are those for the noise-sensitive frequency 4 kHz. For the workers with 10 year occupational noise exposures, the 4 kHz threshold showed a very small rise (perhaps 1 dB) as $L_{EX,8h}$ increased from 75 to 85 dB(A), for both the median and worst decile data. No confidence limits were presented for the fitted curves, but it seems unlikely that the extremely weak relation between $L_{EX,8h}$ and threshold shift would be statistically significant. For the 40-year exposure, the situation was not much clearer. As noise exposure increased from 75 to 85 dB(A), the 4 kHz threshold shift increased approximately 2-3 dB, for both the median and worst decile of the workers. For $L_{EX,8h}$ below 80 dB(A), there was no relationship between exposure and NIPTS. Above 85-90 dB(A), NIPTS rose sharply with increasing exposure.

CONCLUSION: The ISO 1999 method predicted more NIPTS than was observed in the Dutch workers surveyed. These Dutch data show a transition zone between no noise effect and a clear risk to hearing. Below an $L_{EX,8h}$ value of 80 dB(A), daily occupational noise has little if any effect upon the 4 kHz threshold. Above 90 dB(A), most workers show a hearing loss.

4.1.2. Passchier-Vermeer (1988)

This author reviews a number of research studies to establish a database of hearing thresholds considered typical-for-age for males not exposed to noise. This ‘typical’ database shows slightly higher (worse) thresholds-by-age than for screened normal males. These typical data were used in an analysis of hearing thresholds observed in noise-exposed groups reported in the literature of the 1980s.

The thresholds at 4 kHz (the most noise-sensitive audiometric frequency) were considered for 56 groups or samples of noise-exposed workers. Values of $L_{EX,8h}$ ranged from less than 80 dB(A) up to 108 dB(A); representative ages for the groups ranged from 28 years to 53 years. As might be expected, the thresholds showed two general trends for the median and for the worst decile: worse thresholds with increasing $L_{EX,8h}$ and also with increasing age.

One aspect of the analysis is particularly important for present purposes: the occupational samples with $L_{EX,8h}$ equal to or less than 80 dB(A) had 4 kHz thresholds matching the typical-for-age hearing threshold levels, over the age range 30 to 50 years.

CONCLUSION: Noise exposures equal to or less than 80 dB(A) had no effect upon workers’ hearing thresholds at 4 kHz.

4.1.3. Robinson *et al* (1994)

A review study, conducted for the UK Health and Safety Executive, examined the hearing loss which might result from occupational noise exposures with $L_{EX,8h}$ less than 85 dB(A). Data were taken from six studies from Europe and North America, reported over the period 1961 to 1980. The key feature of the analysis was the separation of hearing threshold levels into components due to noise and due to age. Because very small threshold shifts were expected from the low-level noise exposures, the analysis concentrated on hearing threshold data for the most vulnerable frequency 4 kHz.

The data ensemble, covering a range of low-level exposures and years of work in noise, indicated a negligible noise-induced threshold shift for $L_{EX,8h}$ values at and below 75 dB(A). Above 75 dB(A), but below 85 dB(A), long-term noise exposure had some effect, but the amount of noise-induced threshold shift in the subject samples was so small as to be undetectable by practical means in individual cases. Within the exposure range 75-85 dB(A), the noise effect was measurable only in the statistical sense, using groups of exposed individuals. Moreover, the amount of noise-induced threshold shift was so small as to be overshadowed by the loss of hearing associated with advancing age, whether due to natural causes or the insults of everyday living.

CONCLUSION: Noise exposures of 80 dB(A) $L_{EX,8h}$ or less will produce no detectable hearing threshold shift, even after years of exposure.

4.2. HEARING LOSS OVER ALL FREQUENCIES

4.2.1. Flottorp (1995)

A project was undertaken at a tobacco plant in Norway, over the period 1983 to 1994, to monitor the workplace noise and the hearing of exposed workers. The $L_{Aeq,8h}$ was determined at over 140 individual workstations. Over the study duration, the proportion of locations with exposure levels equal to or greater than 85 dB(A) increased from 3% to 13%. Workers in these areas were required to wear ear protectors. The majority of work areas were found to have levels between 75 and 85 dB(A).

Monitoring audiometry was performed annually on all workers (some protected, most not) exposed to an $L_{EX,8h}$ of 75 dB(A) or greater. Over the years, the number of workers surveyed ranged from 232 to 315. The proportion of workers with high-frequency hearing losses, possibly attributable to damage by noise, remained constant at around 15%. These workers were said to have joined the company with a pre-existing hearing deficit. All other workers retained normal or near-normal thresholds over the duration of the project, or exhibited hearing pathology from non-noise causes.

CONCLUSION: When workplace noise does not exceed an $L_{EX,8h}$ of 85 dB(A), the chance of acquiring noise-induced hearing loss is small.

4.2.2. International Institute of Noise Control Engineering (1997)

This international organization set up a Working Party to review current knowledge and practice concerning upper noise levels in the workplace. A number of member societies submitted position papers dealing with existing national legislation, typical levels of industrial noise, and programmes to enforce legislation together with the effectiveness of those efforts.

The Working Party recommended that use of personal hearing protection should be encouraged when engineering and other noise-control measures are unable to reduce the $L_{EX,8h}$ of workers to 85 dB(A). The use of protectors should be mandatory when the exposure level is over 90 dB(A). Workers whose $L_{EX,8h}$ exceeds 85 dB(A) should undergo regular audiometric testing. These recommendations suggest that the Working Party felt that an exposure of 85 dB(A) marked a dividing line between no risk to hearing (or perhaps some minimal-but-acceptable risk) and unacceptable risk. The Working Party did note that an $L_{EX,8h}$ of 75 dB(A) was recommended in Sweden to avoid *any* risk of noise-induced hearing loss in *any* worker, but felt that such a low level was not supported by definitive and unambiguous evidence.

4.3. CONCLUSIONS ON HEARING LOSS FROM LOW-LEVEL NOISE

Overall, occupational hearing loss studies involving low-level noise exposures suggest a region of transition between no effect and a clear noise hazard. Below an $L_{EX,8h}$ value of 80 dB(A), the daily occupational noise seems to have little if any effect upon the 4 kHz threshold of even the most susceptible workers; male workers exposed to a daily average noise level of 80 dB(A) or less showed no hearing loss except that typically expected for their age.

As workplace noise becomes greater, the risk of hearing damage becomes evident. Where noise exceeds an $L_{EX,8h}$ of 85 dB(A), there is a chance of acquiring some degree of noise-induced hearing loss. Above 90 dB(A), the risk of hearing damage becomes plain and progressively more severe for groups with higher noise exposures.

5. TEMPORARY THRESHOLD SHIFT AND EFFECTIVE QUIET

When considering what level might be appropriate for an occupational noise limit, it is relevant to raise the question: *Is there a noise exposure which is known to cause no permanent hearing injury?* The question may be phrased in an even more extreme form: *Is there a noise exposure known to produce no after-effects whatever, either permanent or temporary?*

Research into temporary threshold shift (TTS) has addressed these questions. TTS is an increase (worsening) of the hearing threshold level, for one or more frequencies, which shows recovery once the apparent cause has been removed. Recovery occurs over a period ranging from minutes to hours to days depending on the degree of TTS. Much research was conducted in the 1950s and 1960s, in an effort to understand how noise damages hearing, and to set reasonable damage risk criteria. Several aspects of this research are important for present purposes:

1) There exists a certain magnitude, in dB(A), for a broadband noise which will just *fail to produce* a TTS, no matter how long an individual is subjected to that noise. This level marks the top of a range which has been termed Effective Quiet.

2) Exposure to constant-level broadband noise for very long periods, up to 48 hours, has been shown to cause TTS which grows and then remains constant. This phenomenon is called Asymptotic Temporary Threshold Shift (ATTS); the final value of threshold shift depends upon noise level, but is (by definition) independent of exposure duration.

5.1. INVESTIGATIONS OF ASYMPTOTIC TEMPORARY THRESHOLD SHIFT

5.1.1. Johnson, Nixon, Stephenson (1975)

These researchers investigated ATTS in a military context: what ATTS would be expected in US Air Force personnel exposed to continuous noise during a flight mission lasting as long as 48 hours? The threshold shift at 4 kHz, widely acknowledged as the most noise-sensitive frequency of human hearing, was used to determine a noise level which might produce no ATTS, in other words, a value of Effective Quiet. Groups of subjects were exposed to pink noise (with equal Sound Pressure Levels for the octave bands ranging from 125 Hz to 4 kHz) at 80, 85 and 95 dB(A) for periods of 24 hours and 48 hours. TTS was measured throughout each exposure period, for comparison with each individual's pre-test audiogram. For each exposure condition, the TTS increased rapidly over the first few exposure hours, to approach the asymptotic TTS.

The values of maximum TTS found in this study were applied to various models for growth of ATTS. An extrapolation suggested to the investigators that 0 dB ATTS might be expected at a sound level of 78 dB(A). This estimate of Effective Quiet was not regarded as definitive; further research was needed to cover a wider range of fatiguing sound levels, in order to bracket the desired value for Effective Quiet.

5.1.2. Stephenson, Nixon, Johnson (1980)

Reviewing results from their own earlier studies, and those of other workers, led these researchers to hypothesise that a threshold for ATTS by broadband noise lay in the wide range 65-80 dB(A). Follow-on work was undertaken, to narrow this range. Young male volunteers were exposed to 24 hours of broadband noise at sound levels of 65, 70, 75, 80 and 85 dB(A). TTS growth and recovery were measured throughout each exposure (and recovery) condition.

Stephenson, Nixon and Johnson concluded that there was a range of sound level for broad-band sounds which separated noises which are potentially harmful to human hearing, from noises which are harmless regardless of duration. This range was 75-80 dB(A); in this range, the beginnings of ATTS could be identified after 24 hours exposures. The authors preferred 75 dB(A) as the upper limit for Effective Quiet, for the very long exposure durations tested. They commented that 80 dB(A) produced only a small ATTS which recovered very rapidly, even after a 24-hour exposure.

CONCLUSION: In the context of TTS, no sharp boundary exists between harmless and fatiguing noise exposures.

5.1.3. Mills, Adkins, Gilbert (1981)

These investigators also examined the growth and recovery of ATTS, using broadband noise at levels of 76, 81, 87 and 91 dB(A). For the first portion of their study, exposure duration was 24 hours. The TTS was measured during the exposure and found to reach a maximum at 8 hours into the 24-hour period; thereafter, a degree of recovery appeared to take place in spite of the continuing noise. Further investigations concentrated on the maximum TTS after 8 hours, and recovery in quiet. Regression analysis of the ATTS data against the levels of the broadband noise indicated (by extrapolation) an expected ATTS of 0 dB for a noise of 78 dB(A) lasting 8 hours.

CONCLUSION: A noise exposure of 78 dB(A) would not be expected to produce any TTS after 8 hours.

5.2. A THRESHOLD FOR EFFECTIVE QUIET

Any broadband sound falling within the range of Effective Quiet may be regarded as completely innocuous in terms of hearing damage. In respect of any noise level outside (above) the range of Effective Quiet, the most severe occupational criterion might be: Any noise capable of producing TTS (after an 8-hour exposure) carries a risk of producing a permanent shift of the hearing thresholds. Conversely, any noise which does not produce TTS cannot produce a noise-induced permanent shift of hearing threshold. Research has indicated that sound of 75 dB(A) do not produce consistent and discernible TTS, whereas 80 dB(A) does produce short-lived TTS. If Effective Quiet does have an upper limit, that noise exposure Threshold Level is probably about 78 dB(A).

6. CONCLUSIONS

The Commission of the European Union has proposed a health and safety at work directive which contains a noise exposure Threshold Level of 75 dB(A) for each 8-hour workday. This $L_{EX,8h}$ was chosen to eliminate the risk of noise-induced hearing loss. The 75 dB(A) value appears to be based on International Standard 1999; this standard is flawed and gives a hearing damage threshold which is unjustifiably low.

Overall, occupational hearing loss studies involving low-level noise exposures suggest a slowly progressive region of transition between no noise effect and a clear noise hazard for the two main noise-related effects on hearing capability, i.e. permanent hearing loss and temporary threshold shift.

Studies of permanent hearing loss from low-level occupational noise have indicated that for workers whose $L_{EX,8h}$ exceeds 85 dB(A), there is a chance of acquiring some degree of noise-induced hearing loss. Workers exposed to 80 dB(A) $L_{EX,8h}$ or less suffered no hearing loss beyond the range typically expected for age; noise had no effect upon the hearing at 4 kHz, the most noise-susceptible frequency, even after years of exposure.

Investigations into temporary threshold shift (TTS) have produced results applicable to the transition zone between harmless and harmful occupational noise exposure. Any noise capable of producing TTS (after an 8-hour exposure) carries a risk of producing a permanent shift of the hearing thresholds after years of repeated exposures. Conversely, any noise which does not produce TTS cannot produce a NIPTS. Research has indicated that sound levels of 75 dB(A) do not produce consistent and discernible TTS even after many hours, whereas 80 dB(A) does produce detectable but very short-lived TTS.

The results of this review indicate that the Threshold Level of 75 dB(A) proposed in the draft directive is too restrictive; no permanent injury or temporary effect would be anticipated. If it is possible to specify a unique Threshold Level for hearing protection as a value of noise exposure, above which hearing injury is measurable and significant, and below which no effect is discernible, an $L_{EX,8h}$ of 80 dB(A) seems to be a suitable value. Years of occupational exposure to noise at 80 dB(A) do not produce a discernible NIPTS and only a non-significant temporary threshold shift.

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APPENDIX 1

CALCULATED HEARING THRESHOLDS FOR AGE AND NOISE EFFECT ACCORDING TO ISO 1999

The lower limit of applicability of the standard, an $L_{EX,8h}$ of 75 dB(A), is implicit in the calculation method. For exposure levels above 75 dB(A), and durations ranging from 10 to 40 years, the median NIPTS values, $N_{0.50}$ in dB, for both sexes are given by the equation:

$$N_{0.50} = [u + v \log q]\,[L_{EX,8h} - L_0]^2$$

where L_0 is a cut-off sound pressure level defined as a function of audiometric frequency, with values given in tabular form,

q is the exposure time in years, and

u and v are parameters tabulated as a function of frequency.

The standard gives a table of values for the quantities u, v and L_0 appropriate to the different audiometric frequencies. The values of L_0 have been extracted for examination here.

Table A1: Values of L_0 for each audiometric frequency

Frequency, kHz	L_0, dB
0.5	93
1	89
2	80
3	77
4	75
6	77

Note that L_0 assumes a minimum value at 4 kHz, the audiometric frequency at which noise-induced hearing loss usually appears first. For an $L_{EX,8h}$ of 75 dB(A), the squared term in the equation above equals zero, therefore the median NIPTS is zero. For $L_{EX,8h}$ < 75 dB(A), NIPTS is defined as zero. Another equation allows calculation of various fractiles of the NIPTS distribution; this equation also contains the term $[L_{EX,8h} - L_0]^2$. Therefore, NIPTS at 4 kHz is zero for all members of the population exposed to 75 dB(A) or less.

From the values of L_0 given here in **Table A1**, it may be seen that NIPTS at 4 kHz will be non-zero only when a threshold of 75 dB(A) is exceeded. For NIPTS at 3 and 6 kHz, the threshold value is 77 dB(A). For the lower frequencies, the threshold values are higher still.

To show the influence of the quantity L_0 upon NIPTS, threshold shifts are given in **Table A2** for the frequencies 1–6 kHz, and for various values of $L_{EX,8h}$. Of interest here is hearing loss due to relatively low noise exposures, therefore NIPTS values are given to represent the median of the noise-exposed population and also the most noise-susceptible decile. An $L_{EX,8h}$ of 75 dB(A) yields NIPTS values of zero. Exposures of 76 and 77 dB(A) give non-zero NIPTS values for 4 kHz but rounding to the nearest integer decibel still gives entries of zero.

For an $L_{EX,8h}$ of 78 dB(A), a non-zero value of NIPTS at 4 kHz emerges for the 'tender-ear' decile after 10 years of exposure. After 20 years of exposure, the threshold shift at the median reaches 1 dB. Further exposure duration up to 40 years does not enlarge the 1 dB of NIPTS at 4 kHz, and does not produce NIPTS at any other frequency. A threshold shift of 1 dB is virtually undetectable, and is imperceptible to the person with such a loss.

CONCLUSION: ISO 1999 states a damage risk threshold $L_{EX,8h}$ equal to 75 dB(A). However, NIPTS is not predicted until an exposure of 78 dB(A) is reached.

Returning to **Table A2**, it may be seen that an $L_{EX,8h}$ of 80 dB(A) is the next point of interest: non-zero values of NIPTS are now exhibited for the frequencies 3 and 6 kHz, as well as for 4 kHz, the most noise-sensitive frequency. The NIPTS values are, however, very small. As the noise exposure assumes higher values, 85 and 90 dB(A), it may be seen that NIPTS grows quickly over the exposure duration period up to 10 years, and then less quickly over the period 10–40 years. The growth of NIPTS is faster for the 'tender-ear' decile than at the median; this means that the NIPTS distribution is becoming more disperse with increasing exposure time. Finally, keeping exposure duration constant, it may be seen that increasing values of $L_{EX,8h}$ leads to increasing, in fact rapidly accelerating, NIPTS at any one frequency or fractile. Between 75 and 80 dB(A), NIPTS at the frequencies 3, 4 and 6 kHz hardly grows at all. Above 85 dB(A), NIPTS at these frequencies increases sharply with increasing $L_{EX,8h}$.

HEARING THRESHOLD LEVELS OF A NOISE-EXPOSED POPULATION: THE COMBINATION OF AGE AND NOISE

Having calculated in the previous section the NIPTS at a number of frequencies and for various noise exposure levels and durations, the overall hearing threshold level *H* for any frequency may be evaluated by using the empirical formula given in ISO 1999 (the terms of the equation have been altered slightly for clarity of presentation here):

$$H = A + N - [(A \times N)/120]$$

where *A* is the hearing threshold level, in dB, associated with natural ageing and incurred loss from other causes, and

N is the NIPTS in dB.

The equation is applicable only to corresponding fractile values of *H*, *A* and *N*. This means, for example, that *H* at the worse-hearing decile (10%) will result for the equation applied with the 10% values for *A* and *N*.

Otologically normal population

Values of *A*, age-related hearing loss for a relevant baseline population, are needed. One set of such baseline values is available from standard ISO 7029, giving the variation of hearing threshold with age for various fractiles of the otologically normal male and female populations. The otologically normal population is a screened or selected sample, composed of persons in a normal state of health, free of obstructing wax in the ear canals, without past or present ear disease, and having no history of "undue" noise exposure. The hearing data from ISO 7029 are also included in ISO 1999, and a selection is reproduced here in **Table A3** where values

Table A2: NIPTS, in dB, by ISO 1999 calculations

Exposure duration, yr		10		20		30		40	
	Fractile, %	**50**	**10**	**50**	**10**	**50**	**10**	**50**	**10**
$L_{EX,8h}$ dB(A)	Frequency, kHz								
78	1	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0
	4	0	1	1	1	1	1	1	1
	6	0	0	0	0	0	0	0	0
80	1	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0
	3	0	1	1	1	1	1	1	1
	4	1	2	1	2	2	2	2	2
	6	0	1	0	1	0	1	1	1
85	1	0	0	0	0	0	0	0	0
	2	1	1	1	2	1	2	2	2
	3	3	5	4	6	4	7	5	7
	4	5	7	6	8	6	9	7	9
	6	3	4	3	5	3	6	4	6
90	1	0	0	0	0	0	0	0	0
	2	2	6	4	8	5	9	6	10
	3	8	13	10	16	11	18	12	19
	4	11	15	13	18	14	19	15	20
	6	7	12	8	14	9	15	10	15

Table A3: Hearing threshold levels, in dB, for an otologically normal population.

	Age, yr	**30**		**40**		**50**		**60**	
	Fractile, %	**50**	**10**	**50**	**10**	**50**	**10**	**50**	**10**
	Frequency, kHz								
Males	1	1	9	2	11	4	14	7	19
	2	1	11	3	15	7	21	12	29
	3	2	13	6	19	12	29	20	42
	4	2	14	8	23	16	37	28	55
	6	3	16	9	26	18	41	32	62
Females	1	1	9	2	11	4	14	7	19
	2	1	10	3	13	6	18	11	25
	3	1	11	4	15	8	21	13	30
	4	1	12	4	17	9	25	16	35
	6	2	14	6	21	12	31	21	45

are given for the frequencies 1–6 kHz at the median (50%) and at the worse-hearing 10% point for males and females at various ages.

The values of age-associated hearing loss given in **Table A3** (Database A from ISO 1999) represent normal hearing at age 30, 40, 50 and 60 years, for males and females. These values are intended to be used in combination with the NIPTS values of **Table A2**, to give overall hearing threshold level in a normal (screened) but noise-exposed population. For present purposes, inspection of the *A* values will give a perspective on the significance of actual or potential values of NIPTS. An $L_{EX,8h}$ of 90 dB(A) is accepted as potentially hazardous to human hearing, that is, capable of producing some significant degree of hearing damage in an appreciable fraction of the exposed population. Consider a male worker with an $L_{EX,8h}$ of 90 dB(A) for 10 years. If this individual were in the most noise-susceptible tenth of the population, he would exhibit a NIPTS at 4 kHz of 15 dB or more, as seen in **Table A2**. Assuming that this individual started work at age 20 years, then his 10 years of noise exposure would make his present age 30 years. Reference to **Table A3** indicates that age-associated hearing loss at 4 kHz in the worse-hearing 10% of normal males is 14 dB or more. For this notional noise-exposed worker, the age and noise components are comparable early in his working lifetime. His total hearing loss *H* may be calculated according to the 'compressed addition' formula (see Section above):

	dB
noise	15
ageing	14
total	27

If this notional worker, at the 10% level, were to continue his noise exposure with $L_{EX,8h}$ equal to 90 dB(A), until age 60 years (40 years noise exposure), the situation would change somewhat. The predicted NIPTS would be 20 dB or more, whereas the age-associated hearing loss would have an expected value of 55 dB or more. The age component dominates the total hearing loss. This is not to say that a NIPTS of 20 dB at 4 kHz is insignificant; indeed, if our notional worker had been in quiet employment, his hearing would be significantly better. The relative levels of the two components give a strong compression for the total

	dB
noise	20
ageing	55
total	66

showing which is the more potent influence at 4 kHz after a working lifetime in a noise environment of 90 dB(A).

At the median or 50% level of susceptibility to noise and ageing, the picture is different. For a median male aged 30 working for 10 years in a noise of $L_{EX,8h}$ of

90 dB(A), the hearing threshold level at 4 kHz has components and total of

	dB
noise	11
ageing	2
total	13

At age 60, after 40 years in that same noise, the components and total are

	dB
noise	15
ageing	28
total	39

As the $L_{EX,8h}$ value is reduced, a change may be seen in the relative importance of the noise and age components. The NIPTS values become smaller while the age-associated hearing loss remains constant. For an $L_{EX,8h}$ of 80 dB(A), the NIPTS values of 1 or 2 dB are insignificant in themselves, and will make no noticeable contribution to overall hearing loss, regardless of age.

CONCLUSION: NIPTS values resulting from an $L_{EX,8h}$ of 80 dB(A) are small in comparison to the age-associated hearing loss of a **normal** population.

Unscreened population

It should be kept in mind that the above comparison of the age and noise components relates to the otologically normal population termed Database A in ISO 1999. Such a population is a selected sample, screened to eliminate factors that may have resulted in hearing loss. As the opportunity for pathology increases with age, the otologically normal fraction of the population decreases as age increases. In other words, otologically normal individuals may be a high proportion of the younger population, but normality becomes progressively rarer in the older age ranges. Thus, the screened population of Database A is not a faithful representation of the general or typical population, particularly in the older age ranges. This distortion is taken account of in ISO 1999: the standard permits the use of different databases to represent the effect of age upon hearing threshold level in the population not exposed to occupational noise. Database A is unique and fully specified, to represent the hearing threshold levels of otologically screened persons; this database has been seen and used above. The ISO standard also gives a Database B, intended to represent the thresholds of a typical population of unscreened persons, both male and female, of various ages. The alternative Database B is not uniquely specified, but can be chosen by the user. The typical or B population should be matched in all respects save for noise exposure to the population being evaluated. An example Database B is given in ISO 1999. The example, resulting from hearing surveys performed in the USA in the 1960s, is considered representative of an unscreened population of an industrialised country. Median and worse-hearing decile values of better ear hearing threshold level have been extracted from Database B of ISO 1999, and are presented in **Table A4**.

ISO 1999 offers some advice on the choice of database, that is, between normal and unscreened populations. For a noise-exposed population, if the effects of otological irregularities and of non-occupational noise exposure are not to be considered (or cannot be accurately assessed), then the more appropriate database will be that from an unscreened population; Database B would be a relevant population.

Consideration should be given to the relative importance of the *A* and *N* components of hearing threshold level, this time employing the *A* values of **Table A4**. For a typical or unscreened male worker at the 10% level of noise susceptibility, a recognised noise hazard of $L_{EX,8h}$ equal to 90 dB(A) for 10 years (age 30) would give an *H* at 4 kHz as

	dB
noise	15
ageing	38
total	48

Table A4: Hearing threshold levels, in dB, for an unscreened population

	Age, yr	**30**		**40**		**50**		**60**	
	Fractile, %	**50**	**10**	**50**	**10**	**50**	**10**	**50**	**10**
	Frequency, KHz								
Males	1	0	10	3	15	5	16	6	21
	2	2	13	4	19	8	28	10	43
	3	9	20	13	41	19	51	30	62
	4	10	38	17	50	26	54	36	68
	6	18	32	24	62	31	62	46	80
Females	1	1	9	2	13	4	16	7	21
	2	1	9	2	13	6	23	8	29
	3	4	13	6	18	9	26	16	37
	4	4	16	6	18	9	26	17	43
	6	12	25	15	31	20	45	29	57

If this same noise exposure were continued for a total of 40 years (age 60), the components and total would be

	dB
noise	20
ageing	68
total	77

From these sample values, it may be seen that the influence of age and other factors that cause hearing loss, such as certain diseases or medical treatments, are more potent than that of a working lifetime in an $L_{EX,8h}$ of 90 dB(A). This conclusion holds also for the median male of an unscreened population, and also for other audiometric frequencies less affected by noise. For lower noise exposures, the inequality becomes greater still. For an $L_{EX,8h}$ of 80 dB(A), the predicted NIPTS values of 1 or 2 dB are not only insignificant in themselves, but will make no detectable contribution to overall hearing loss, regardless of age.

CONCLUSION: NIPTS values resulting from an $L_{EX,8h}$ of 80 dB(A) are insignificant in comparison to the hearing loss associated with ageing and adventitious pathology in a **typical** or unscreened population.